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PRELIMINARY OBSERVATIONS OF METEOR IMPACTS ON THE LUNAR SURFACE

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ABSTRACT

The feasibility of observing meteor impact on the lunar surface using a land based telescope and photo-electric detector pulse technioues is presented. An instrument to observe these impacts was designed and fabricated. Preliminary observations were performed at Lowell Observatory on a 20 inch refracting telescope during November 1966. The data for 19 November,1966, during which probable impacts were observed is presented. Recommendations for further observations are included.

FOREWORD

This document represents the final report on NASA Contract NASW-1413. The program initiated under this contract called for the development of a photo-electric detection instrumentation system with which to observe meteor impacts on the lunar surface using a ground based telescope. Observations were performed at Lowell Observatory in Flagstaff, Arizona, over a fifteen day period including the Leonid shower during November 1966. The observation results as well as description of the instrumentation are included in this report.

The co-principal investigators for this program were Dr. G. Davidson of AS&E, physicist, and Dr. F. Franklin of the Smithsonian, astronomer. The project engineer at AS&E was Mr. Orr Shepherd. Dr. J. Carpenter provided the theoretical foundations for the experimental efforts, and Dr. L. Sodickson contributed to instrument optical design.

We gratefully acknowledge the cooperation and support given us by the Lowell Observatory, and in particular Dr. John Hall. We would also like to thank Dr. M. Annis of AS&E for his support and encouragement in this project.

1.0 INTRODUCTION

Consideration of the possibility of observation of meteors impinging on the moon goes back about 75 years to the suggestion of W. H. Pickering (Reference 1) that, in any thin lunar atmosphere, luminous meteor trails must exist. He and others (References 2 - 6) assumed that the surface density of the lunar atmosphere was 10^{-4} to 10^{-5} that of the earth. However, more recent information using lunar occultation of radio sources places an upper bound on the surface density of the lunar atmosphere of about 10^{-13} that of the earth (Reference 7); consequently, no luminous trails are expected.

La Paz (Reference 5) concluded that for an atmosphereless moon, about 100 meteor impacts per year on the lunar surface should be easily observable from the earth. His calculation assumed the kinetic energy of the meteor was released in an explosive manner. After correcting for non-black-body radiation, he concluded the explosion should have a brightness about equal to that of the solar disk.

Haas (Reference 6) reports the lack of visual observation of a single impact flare after 65.7 hours monitoring of the dark portion of the moon but does report sighting 10 luminous trails. He concludes by a statistical argument that these trails were not produced by meteors passing within the field of view of his telescope in the terrestrial atmosphere and, hence, must be lunar in origin. These trails are not, however, consistent with the radio measurements of the tenuousness of the lunar atmosphere.

More recently (Reference 8) several astronomers conducted an unsuccessful search for impact flares on the darkened portion of the lunar disk. Since, we have a fair estimate of the meteor flux incident on the earth, from radio, visual, and photographic observations, we know the approximate meteor flux incident on the lunar surface. Hence, negative results of past observations must be explained. We believe the lack of observed impact flares is due to one or more of the following factors:

1. The short duration of the impact flare. From laboratory measurements of impacts length of the impact flare is of the order of 10^{-6} sec (Reference 9);
2. The overwhelming effects of terrestrial aerosol scattering of light from the bright lunar crescent; and
3. The nature of the lunar surface material may allow deep penetration of the impacting meteors with a consequent reduction in the effective luminous efficiency.

2.0 TECHNICAL BACKGROUND

2.1 Meteor Flux Estimate

Many estimates of the sporadic meteor flux on the earth's atmosphere have been made from radio, visual, and photographic measurements. Alexander, et al (Reference 10) and Gault, et al (Reference 11) list several such estimates and compare them with rocket and satellite measurements.

In this report we use the Hawkins and Upton formula (Reference 12) as modified by Whipple (Reference 13). This modified form for the cumulative flux on the earth is

$$F_{>m} = \frac{3.33 \times 10^{-15}}{m^{1.34}} \quad \text{(meteors/m}^2\text{-sec}$$

where $F_{>m}$ is the cumulative flux of meteors with mass greater than m grams. A comparison of this rate with earlier reported rates is shown in Figure 1.

To account, approximately, for the reduced gravitational attraction of the moon as compared to the earth, we reduce this flux by a factor of three.

The observed area of the lunar surface is $A_M = 2\pi r^2$, where r, the lunar radius, is 1,738 km. Hence the area of interest is $1.89 \times 10^{13} m^2$ and the cumulative rate is

$$N_{>m} = \frac{F_{>m}}{3} A_M = \frac{2.1 \times 10^{-2}}{m^{1.34}} \quad \text{(meteors/sec)}$$

Hence for meteors of 1, 5, 10, and 100 grams, the rate of impact on the observed lunar surface is every 47.7 sec., 6.9 min., 17.4 min., and 6.3 hrs. respectively.

CUMULATIVE METEOROID IMPACT RATES NEAR THE EARTH

REF. 13

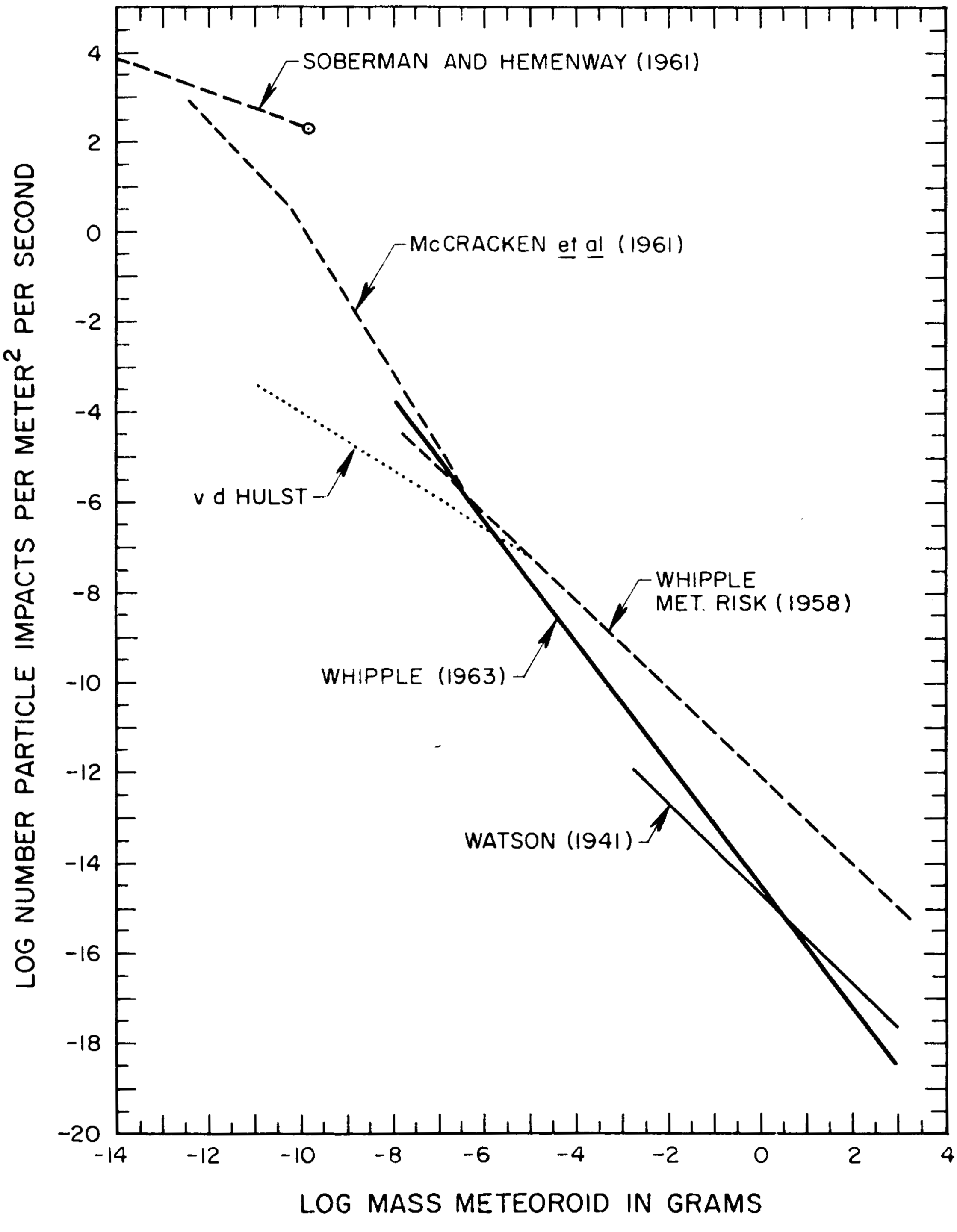


Figure 1

2.2 Luminous Efficiency

Meteors can impact on the lunar surface with velocities between 3 km/sec and 80 km/sec. Laboratory studies of multi-gram projectiles are as yet restricted to velocities less than 20 km/sec. However, information from these studies is of interest in determining the phenomena of hypervelocity impact by meteors.

The slowing down or stopping of a hypervelocity particle is accompanied by a flash of light. The peak luminosity (I_p) over the visible portion of the spectrum was found, empirically, by Gehring and Charters (Reference 9) to be given by

$$I_p = C\,A\,v^n$$

where the proportionality factor C depends principally upon the properties of the target, A is the projected area of the projectile ($\pi d^2/4$) and the exponent n lies between 3 and 9. The efficiency of conversion of the kinetic energy to visible light for the laboratory experiments performed by these investigations ($v \approx 3$ km/sec) was of the order of 10^{-5}. However, if this relationship holds at an average velocity more appropriate to meteor impact (30 km/sec), the efficiency of conversion is of the order of 10^{-3}.

Observations of meteors in the earth's atmosphere also yield values of the order of 10^{-3} for the efficiency with which kinetic energy is transformed to visible radiation. For meteors in the velocity range near 10 km/sec, the luminous efficiency is usually written as (eg. McCrosky, Reference 14)

$$\tau = \tau_o v$$

where v is the meteor velocity. McCrosky's data on aluminum projectiles fired into the earth's atmosphere from a rocket yields:

$$\tau_{o(Al)} = 9 \times 10^{-10} \text{ (sec/cm)}$$

for a velocity of 14.4 km/sec. Thus τ_{Al} is 1.3×10^{-3}.

In a more recent work (Reference 15) using steel pellets fired from a rocket above the atmosphere, McCrosky and Soberman find a value of

$$\tau_{o(steel)} = 8 \times 10^{-19} \text{ (cgs and } M_{pg})$$

at about 8 km/sec, where M_{pg} is the photographic magnitude. Using the definition of M_{pg} (Reference 14)

$$M_{pg} = 22.8 - 2.5 \log I \text{ (ergs/sec)}$$

yields

$$\tau_{o(steel)} = 1.04 \times 10^{-9} \text{ (sec/cm)}$$

Thus for velocities of approximately 10 km/sec the observed value of $\tau_{(steel)}$ is 1.04×10^{-3}. Correcting for the fraction of iron in a stony meteor yields a value of approximately 2×10^{-4} as a lower limit.

For the purposes of this report we approximate the light output upon hypervelocity impact by

$$E = \tau \, (1/2 \, mv^2)$$

and choose τ to be 10^{-3}.

From the experiments of Gehring (Reference 9) for hypervelocity impact of aluminum and steel projectiles on sand and granite at velocities of about 2.5 km/sec, the typical pulse lengths of the light flashes vary from a few tenths to a few microseconds. In this report we will choose one microsecond for the pulse duration.

2.3 Signal Strength

For meteor impact on the moon, the energy per unit area incident on the earth is then

$$\frac{E}{4\pi R^2} = \tau \frac{mv^2}{8\pi R^2}$$

where R is the average earth-moon distance (about 384,000 km).

To obtain typical numbers, let us assume that the velocity of the impacting meteor is 30 km/sec, the average photon energy is 3 ev, and the pulse length of the light flash is 1μ sec. Then for a τ of about 10^{-3} we find the photon flux at the earth to be

$$J = 0.05m \text{ (photons/cm}^2 - \mu \text{ sec)}$$

where m is the mass in grams.

This photon flux can now be compared directly with the photon flux reaching the earth at full moon. This flux is approximately:

$$J = 3 \times 10^5 \text{ (photons/cm}^2 - \mu \text{ sec)}$$

To permit an equal photon flux rate at the earth (for 1 μ sec only) would require an impacting meteor with a mass of about 10^7 g. Using an extreme extrapolation of Whipple's rate, we would expect only a few such massive meteor falls within recorded history. Furthermore, the shortness of the expected flash under such conditions would add uncertainty to the definitiveness of the observation. The only hope for observation lies in using the dark portions of the observed lunar face.

2.4 Interfering Backgrounds

The possible backgrounds to consider in observing the dark face of the moon are:

1. Scattering of light from the sunlit portion of the lunar disc by aerosols in the earth's atmosphere and by the telescope optics.

2. Reflected earth light from the dark region of the moon.
3. Airglow in the earth's atmosphere.
4. Meteors impinging on the earth's atmosphere.
5. Detector noise.

The brightness of the sunlit portion of the lunar disc is lowest at times near new moon. Scattering of light originating from the bright lunar crescent in the earth's atmosphere will determine the angle of closest approach of the viewing field to the crescent. This scattering is more pronounced for observation from low altitude observatories. In order to make the contribution due to scattering equal to the reflected earthlight, the background due to aerosol scattering should be less than 10^{-5} of the intensity of the bright crescent. This condition can be met with high altitude observations. Scattering in typical telescopes is minor and should allow one to approach to within a few arc-minutes of the crescent.

The reflected earthlight from the entire lunar disc near new moon is approximately 10^{-5} of the total intensity from the full moon. This yields a value for earthlight intensity at the earth (I_{EL}) in the region near 4000 Å of

$$I_{EL} \approx 4 \times 10^{-13} \text{ (watts/cm}^2 \text{ - 1000 Å)}$$

This is equivalent to about 1 photon/cm^2 - μ sec in the 1000 Å bandwidth.

Airglow emission (I_{AG}) in the region near 4000 Å is roughly (Reference 16)

$$I_{AG} \approx 10^{-11} \text{ (watts/cm}^2 \text{ - ster - 1000 Å)}$$

The solid angle subtended by the moon is

$$\Omega_{moon} = 6.4 \times 10^{-5} \text{ (ster.)}$$

Thus, for a field of view just covering the lunar disc, the background due to airglow would be 6.4×10^{-16} watts/cm^2 - 1000 Å or approximately 10^{-3} photons/cm^2 - μ sec in the 1000 Å bandwidth.

To estimate the interference due to meteors striking and fluorescing in the earth's atmosphere, let us consider two meteors of equal mass and kinetic energy. Assume one traverses the earth's atmosphere at a distance of 100 km from the detector and assume the other impacts on the lunar surface.

Using the $1/r^2$ law, the energy received per unit area of the detector would be 10^7 times greater from the closer meteor than from the one striking the moon if the efficiencies of conversion into visible light of the kinetic energy of the meteors were equal.

The length of the light flash from hypervelocity particles impinging on solids is of the order of one microsecond. The length of the flash of light from a meteor with a mass of the order of a gram (the size of interest here) incident on the atmosphere is of the order of 10^{-1} seconds. Hence, there is a reduction by a factor of 10^5 in the intensity at the detector due to the length of the light pulse from the meteor in the earth's atmosphere as compared to the intensity received from lunar impact. Since a filtering network for the detection electronics can be constructed to respond only to characteristic frequencies in the megacycles per second region, it is the intensity and not energy which is of interest. The intensity from a terrestrial meteor will be approximately 10^2 times that received from an equal mass meteor impacting on the moon.

Thus, the detection system will be capable of detecting meteors entering the earth's atmosphere within its field of view with 1/100 of the mass of the minimum mass particle detected on the moon. Once this value is set the background may be estimated knowing the meteor flux at the earth.

Photomultipliers are available in which the thermal noise contribution is small compared to the background due to earthlight when used with any telescope of reasonable size.

2.5 Shower and Sporadic Meteors

The expected flux of meteors discussed in Section 2.1 is as noted for the sporadic component only. In addition to this continuing flux, periodically throughout the year as the earth intersects the orbits of various comets, large increases in the meteor flux are observed. Apparently these large increases are due to collisions of the earth with cometary debris which has been scattered along the comet's orbit. These periods of increased meteor flux then hold the promise of allowing the collection of data at a more rapid rate than that predicted by the use of the sporadic flux rate if the cometary debris possesses particles of sufficiently large mass.

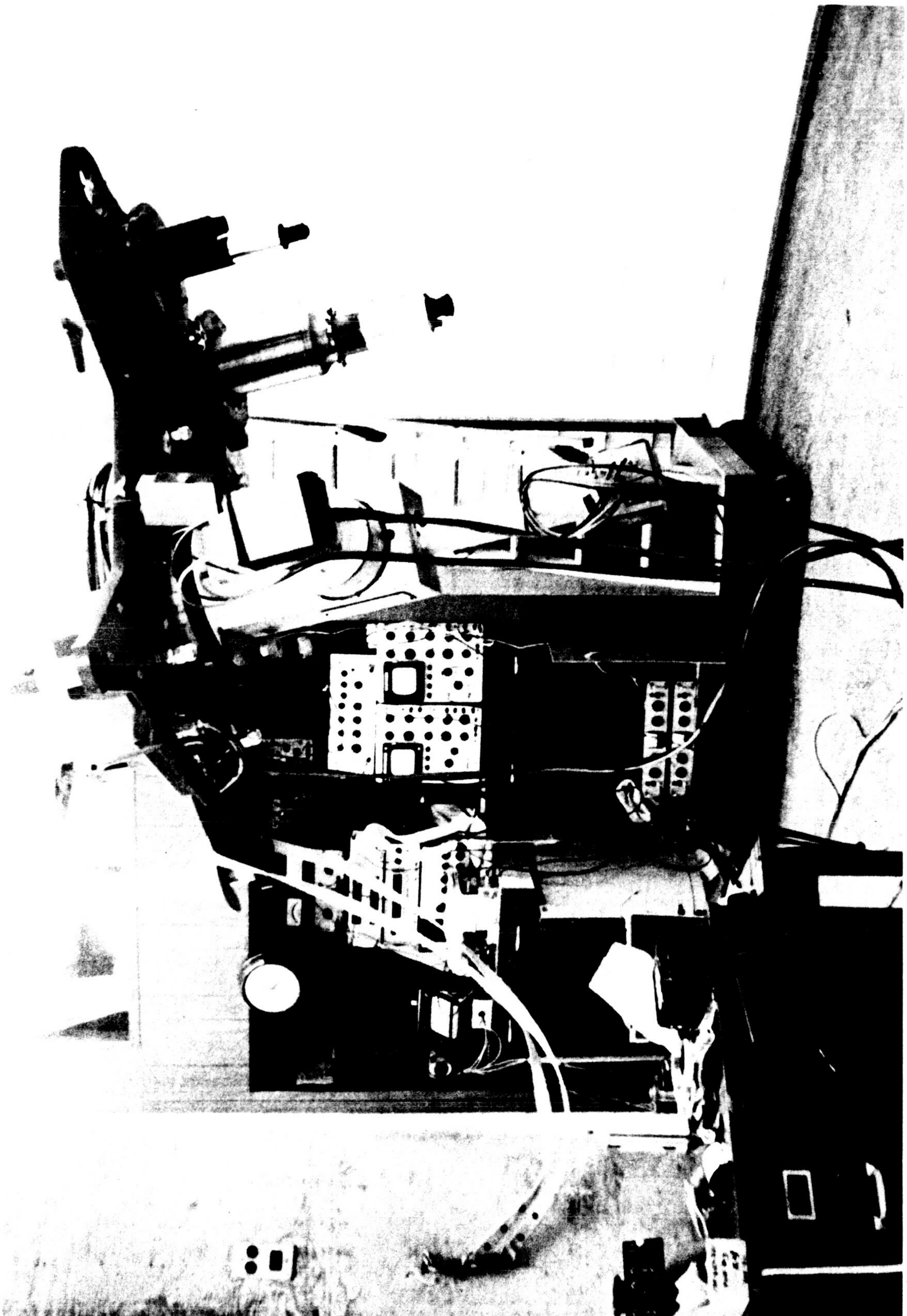
3.0 INSTRUMENTATION

The experimental apparatus consisted of an instrument which was mounted on the telescope, and the associated electronics which was located on the observing stand. Figure 2 shows the experimental setup at the Lowell Observatory 20 inch Morgan refractor.

Figure 3 is a diagram of the instrument. The instrument was mounted directly to the telescope with no provisions for focussing adjustment other than shims which could be put between the instrument and the telescope. This method allowed the position of the telescope image plane to be adjusted to within 0.090 inches of the instrument image plane. With the f/16 telescope optics, this represented a maximum image dispersion of approximately 0.006 inches due to defocussing. A lunar image was required so that a mask could be used to blank off the illuminated region of the moon.

A ring mount was located in the instrument image plane, into which a second ring containing the mask could be mounted. With this arrangement the mask could easily be rotated about the lunar disc center point. The masks were made of paper with several coats of a black velvet spray paint. The lunar terminator was located on each mask by projecting 35 mm slides of the moon in various phases onto the mask paper and tracing the terminator. The projected image diameter was scaled so that it was equal to the lunar image diameter using the 20 inch refractor.

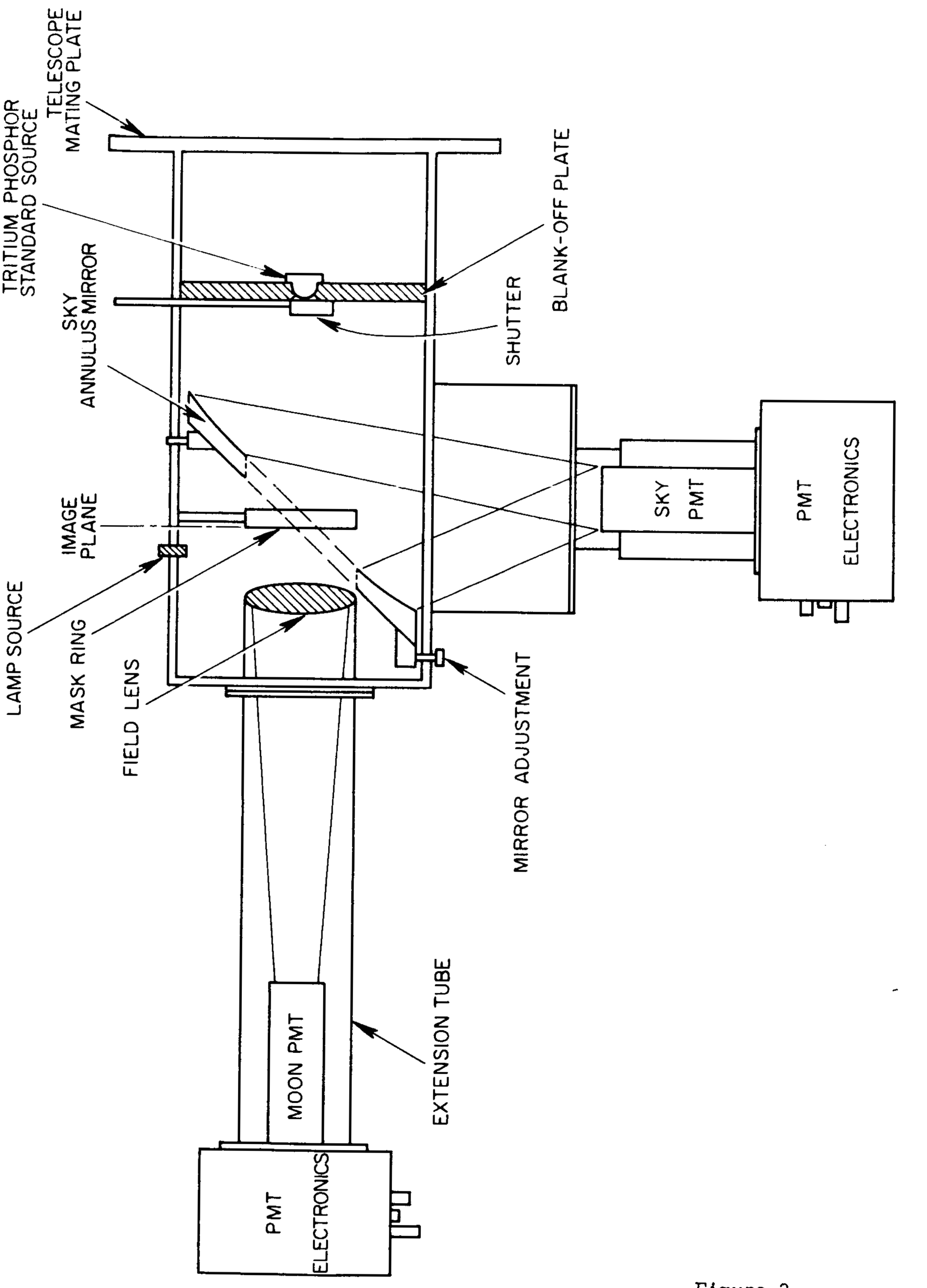
There was also a screen mounted on a mask ring which was placed in the focal plane to allow a visual check on alignment and focusing. An access port in the side of the instrument was provided to allow changing and adjustment of the masks and screens. A quasi-field lens was located behind the mask ring. This lens was a 3 1/8 inch diameter coated achromat with a 19 1/2 inch focal length.



DS-001

EXPERIMENTAL SET-UP AT 20INCH REFRACTOR
LOWELL OBSERVATORY

Figure 2



INSTRUMENT DIAGRAM

Figure 3

The moon photomultiplier was mounted in an extension tube so that its photocathode was 14 inches behind the lens. This location of the photocathode was chosen so that all of the lunar rays fell within a two inch diameter circle. The primary purpose of using a defocussed image was to eliminate the effects of different photocathode sensitivities for different regions on the cathode.

In order to observe an anular ring of sky surrounding the moon, a mirror was positioned in the optics intersecting the image plane at a 45 degree angle. The purpose of the mirror was to collect and focus incident sky radiation onto the cathode of a second (sky) PMT. The mirror was spherical with a 14 inch focal length. It was of elliptical outline with a seven inch minor axis and a 9.9 inch major axis. In the center there was an elliptical hole with a 3 3/8 inch minor axis. The mask ring was mounted within this cut-out. The mirror was fabricated from plexiglass which was machined, polished, and overcoated with aluminum and silicon monoxide. The mirror mount in the instrument was adjustable to provide a small amount ($\pm 3^{o}$) of angular adjustment. The photocathode of the sky PMT was located approximately nine inches below the center of the instrument focal plane. On this PMT a focusing adjustment of $\pm$ 1 inch was provided. The image formed with this mirror was mostly contained within the 2 inch diameter of the sky PMT photocathode.

A sliding blank-off plate could be inserted between the focal plane and the telescope interface to block the light to the two multipliers. This was used to check the dark noise of the PMT. There was a shutter on the plate which, when operated, exposed a tritium phospher source to both PMTs. This stable source of radiance provided a means of calibrating the PMT gain and relating it to laboratory measurements. The shutter also prevented the phospher from being excited by ambient light when the blank-off plate was removed.

Secondary calibration sources were provided for each PMT. These were miniature tungsten filament lamps. The sky PMT source was located on the side of the instrument directly over the focal plane. To use the moon PMT secondary source, it was necessary to remove the extension tube from the instrument and mount the source on the open end of the tube. These sources were connected to individual power supplies and the current adjusted such that the PMT anode currents were eaual to the levels measured during observation. Thus, PMT statistics could be compiled after observation had terminated.

The optical alignment of the instrument, when first integrated with the telescope, was done visually. A screen was put in the mask ring and the lunar image was inspected for image quality and sharpness. The screen was then removed and a hand axial scan performed to observe the image in the axial direction (fore and aft) with respect to the focal plane. The original mounting configuration appeared to locate the instrument focal plane coincident with the telescope focal plane. A viewing screen was then put in the extension tube where the PMT cathode would be located. The defocussed image from illuminated portion of the lunar disc was viewed the the instrument shimmed until the image fell within, and was concentric with, a 2 inch diameter circle. The screen was then put in place of the sky PMT and the image observed. The mirror was adjusted until symmetry was observed. As an alignment check, a star was scanned in right ascension and then in declination. The sky channel was not symmetric and vignetting was apparent. The mirror was readjusted and the symmetry of the anular ring verified. Some vignetting was anticipated due to the seven inch diameter hole at the interface plate.

Figure 4 is a diagram of the system electronics. The moon PMT has a 1.1 K ohm load resistor from anode to ground. A d.c. amplifier with a gain of 10 provided a voltage proportional to anode current. This voltage was

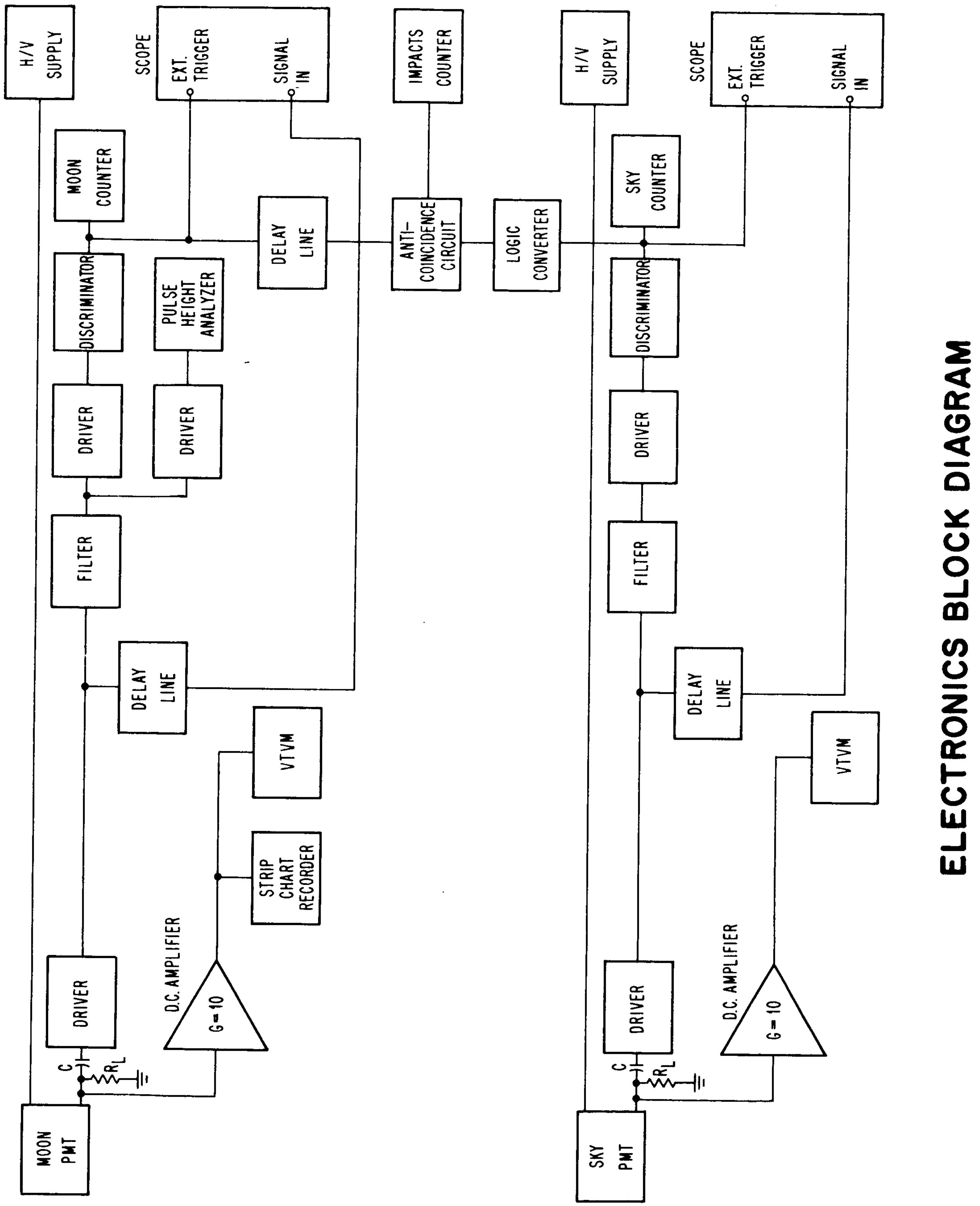

ELECTRONICS BLOCK DIAGRAM
H/V SUPPLY
SCOPE
EXT. TRIGGER
SIGNAL IN
IMPACTS COUNTER
MOON COUNTER
DELAY LINE
ANTI-COINCIDENCE CIRCUIT
LOGIC CONVERTER
SKY COUNTER
DISCRIMINATOR
PULSE HEIGHT ANALYZER
DRIVER
FILTER
VTVM
STRIP CHART RECORDER
D.C. AMPLIFIER
G = 10
C
R_L
MOON PMT
SKY PMT

Figure 4

monitored on a VTVM. A strip chart recorder produced a permanent record. The PMT pulses were capacitively coupled into a line driver which drives the RG/58U cable between the instrument and the system electronics. The filter provided a one microsecond integration period of the PMT pulses. The PMT output was also differentiated with a time constant of 10 microseconds, thus isolating any slow variations in PMT output signal from the pulse counting system. The filter output was sent through a driver to the 400 channel pulse height analyzer (PHA). The PHA was operated with its base line control set so that a zero volt input pulse would enter PHA channel zero. The PHA internal discriminator was set so that any pulses entering the PHA below Channel 6 were not counted. A PHA gain adjustment allowed the operator to select a gain so that the incoming pulses were analyzed with a dead time of less than 10 percent. A printer was connected to the PHA and this provided a printed record of the PHA live time and the pulse counts in each individual channel.

The filter output was also sent to a second driver which fed a discriminator. This discriminator generated a 6 volt, 1 microsecond pulse when an input pulse exceeded a threshold value. The discriminator output was fed to the moon channel counter. In addition the discriminator output was fed through a 3.5 microsecond delay to the anti-coincidence circuit. The discriminator output pulse was also used to trigger the oscilloscope which displayed the moon PMT pulse. The displayed pulse was taken before the filter and delayed by 6 microseconds. This delay was inserted to allow for the time delay in the discriminator and to allow the pulse to be displayed in the central region of the CRT along the horizontal (time) axis.

The sky channel is similar to the moon channel except that no pulse height analysis was required for the sky PMT.

4.0 OBSERVATIONS

The instrument and its associated equipment arrived at Lowell Observatory, Flagstaff, Arizona on 5 November 1966. This period was chosen to allow observation before, during, and after the Leonid shower so that we might differentiate between the contribution of sporadic and shower meteors. The experimental setup was removed from the telescope on 20 November 1966. A condensed log of the observing period is listed in Table 1.

The actual observation time listed indicates only the time during which valid data could be taken. The system was in operation or standby throughout most of the scheduled observation time.

During the morning terminator, many system problems were encountered. The cool temperature within the dome adversely effected the PHA and printer. Electric blankets were used to warm the equipment.

The high quantum efficiency PMT's which were originally planned to be utilized developed an after-pulsing effect which yielded non-Poisson statistics. Two additional substitute S-11 tubes were supplied by the manufacturer, but these also gave unsatisfactory noise spectrums. A spare RCA 6217 (S-10) PMT was finally installed in the Moon channel. The sky channel used one of the replacement S-11 PMT's. Since the sky discriminators were set at high levels and a low false alarm rate could be tolerated, the use of a relatively noisy tube in this channel was permissible.

The telescope had no lunar tracker. Therefore, it was necessary to correct, periodically, the RA drive rate, the declination, and the dome floor height. Each of these operations generated transients which introduced

Table 1

Log of Observations

Date	Weather Condition	Scheduled Observation Time (Hours)	Actual Observation Time (Hours)
11/6/66	Heavy Clouds	6	0
11/7/66	Rain	5	0
11/8/66	Scattered High Cirrus	3 1/2	0
11/9/66	Clouds	2 1/2	0
11/10/66	Scattered High Cirrus	1 1/2	Background Measurements
11/11/66		1/2	0
11/12/66		0	0
11/13/66		0	0
11/14/66	High Cirrus	1/2	0
11/15/66	Heavy Cirrus	1/2	0
11/16/66	Heavy Cirrus	1/2	0
11/17/66	Clear	1 1/2	2 hours
11/18/66	Heavy Cirrus	2	0
11/19/66	Clear	3	3 hours

false counts into the system. During this time in which these corrections were being made, the system was disabled and no data were taken. Approximately five minutes of data could be taken before realignment was reouired. Realignment was performed in approximately one minute. After every second or third alignment, the PHA memory was printed out.

One hour prior to sunset the telescope was trained on the moon. The observing screen was mounted in the mask ring of the instrument and, by moving the telescope, the illuminated limb of the lunar image was aligned with perimeter of the mask ring. When this alignment had been obtained, the ten inch finder telescope was aligned on the prominent lunar feature. The telescope was then swung off the moon and the alignment procedure using the finder was verified. A tracking eye piece holder was fabricated for this experiment. The eye piece was of low magnification and had a cross-hair reticle. The holder allowed the eye piece to be moved so that any part of the lunar disc could be centered on the cross hairs. Next, the appropriate mask was mounted in the instrument and oriented so that it covered symmetrically the illuminated portion of the image. The moon PMT was then mounted on the instrument.

At approximately sunset a PMT high voltage of 500 volts was turned on and the anode currents were monitored. The high voltages were increased until approximately 200 microamps of anode current was obtained. These currents were observed to decrease in an exponential manner and become constant shortly before astronomical twilight. At this time PHA accumulation was initiated and the data run begun. During the data run the PMT anode current was maintained in the 200 microamp region by high voltage adjustment.

Prior to starting a data run, the system electronics were calibrated using a pulse generator, The signal cables were disconnected from each PMT and connected to a pulse generator. A one microsecond pulse at a low repetition rate was sent through the system. PHA channel number and discriminator level were correlated with pulse amplitude at several points. The operation of the counters and the anticoincidence gate was confirmed. The PMT's were then connected into the system and the anode current monitor d. c. amplifier output was set at zero volts with the PMT high voltage off. Approximately 10 millivolts of drift were observed at the amplifier output, caused by amplifier temperature changes. During a data run the amplifier output voltage was in the one volt region.

The moon PMT was set up to view the secondary calibration lamp. By adjusting the lamp filament current until the PMT anode current approximated the predicted level, a reasonable statistical check on the system was obtained. These data were accumulated in the PHA for 600 seconds and then printed out.

When the data run was terminated, the telescope was pointed at a star. It was determined that the illumination from a first magnitude star was approximately eoual to the earth-light from the full lunar disc. Thus, by comparing the anode currents when viewing the star and those observed for the moon, a measure of the scattering caused by the moon's albedo was obtained. This was an approximate measurement due to the zenith angle and time differences between observations. It was concluded that most of the scattering observed on the clear nights was caused by dirt on the first and second surfaces of the 20 inch objective.

The star was observed for a period long enough to provide adeouate PHA statistics. Then the electronics were again calibrated with the pulse generator.

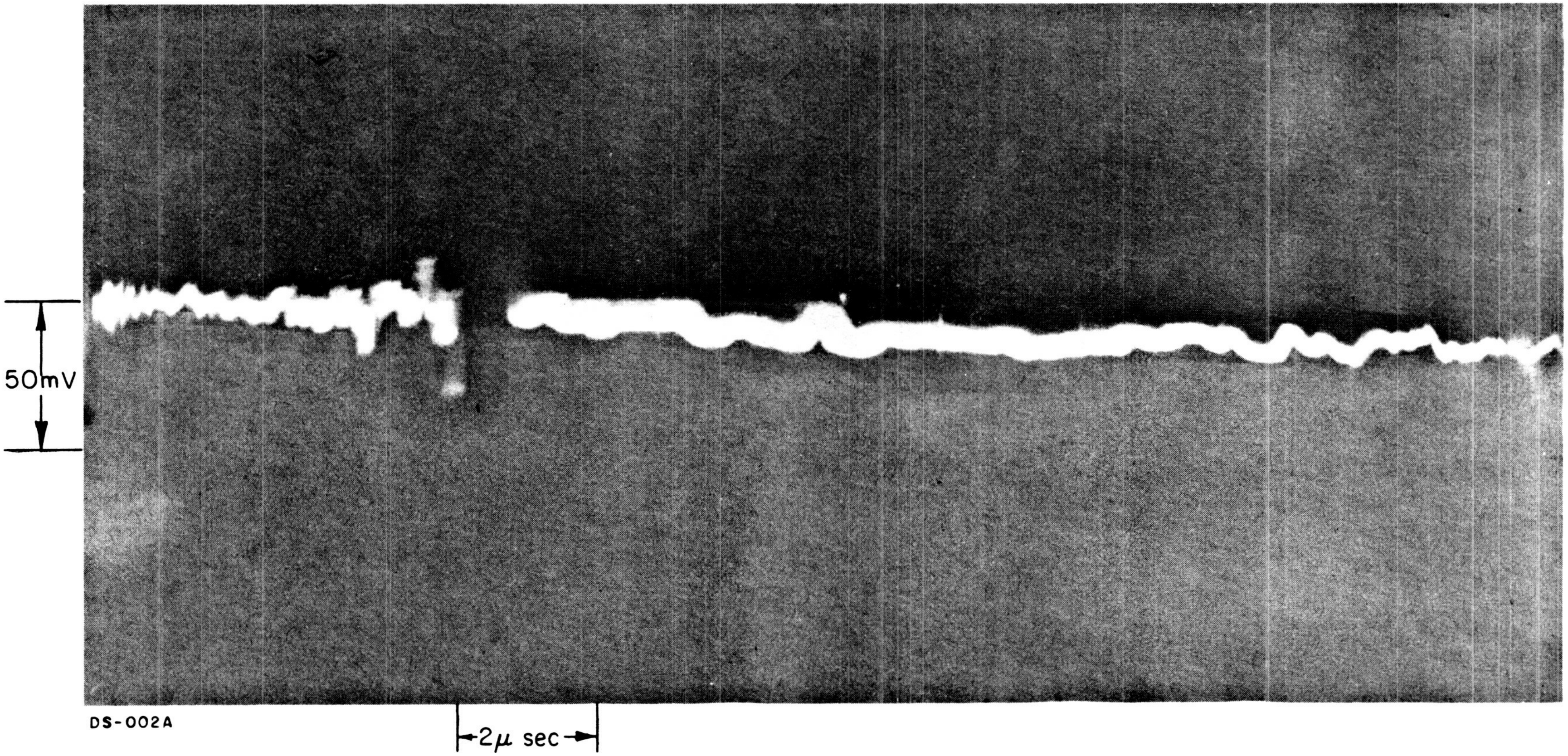
4.1 Data

The data listed in Table 2 were obtained during the 19 November 1966 observation period. For each data run the following measurements are listed:

$E_{b\ moon}$	-	Moon PMT high voltage
I max	-	Maximum anode current during data run
I min	-	Minimum anode current during data run
Time start	-	Local time at which data run was initiated (MST)
Time end	-	Local time at which data run was ended (MST)
Total live time	-	PHA live time
PHA gain	-	PHA input amplifier gain

The data in Table 2 are tabulated in the form of counts observed in the individual channels during the particular run.

Run 80 was a 10 minute data run with the secondary calibration lamp as a source. Runs 82 through 86 were moon runs in which no high amplitude pulses occurred, as can be noted by the absence of counts in the higher channels. Run 87, for which the PHA gain was increased, displayed a great number of high amplitude pulses. At the end of this run the PMT wave forms at various points in the system were observed to confirm proper system operation. Run 88 was ended immediately after the pulse was recorded by channel 108. There was no associated pulse from the sky circuit. The scope photograph is shown in Figure 5. This pulse peak is off scale but it can be noted that it is approximately 1 microsecond wide from the interruption of the trace. Of all the high amplitude pulses recorded, only the pulse in channel 108 was large enough to trigger the oscilloscope. After the large pulses had been observed no changes were made in any system adjustments. Runs 89 through 94 were on the moon. Runs 95 and 96 were on α Andromeda, a star of 2.1 magnitude. An anode current of 22 microamps was recorded on the star and 6 microamps when the telescope was pointed at the dark sky. From the data it can be concluded that scattering of light from the bright



SCOPE PICTURE OF HIGH AMPLITUDE PULSE
RUN No. 88 — PHA CHANNEL 108

Figure 5

crescent was approximately an order of magnitude greater than the earth light. Run 97 was made on the secondary calibration lamp. These runs show the return of normal statistics. The PHA calibration was 3.1 millivolts/channel with a gain of 154.

The mask used for this viewing period was made for an 8 day moon. The area of the disc observed was approximately 45 per cent of the total.

The sky channel recorded 5 counts during the evenings observation. No simultaneous counts on the moon channel were noted.

When the data runs had been completed (Run 97) an attempt was made to obtain additional PMT statistics by observing Jupiter, but scattered high cirrus clouds caused the PMT anode current to vary by approximately a factor of 2. Therefore, no statistics were compiled and the telescope testing was ended at 0600 MST.

The intensity of the Leonid shower was observed by stations in the Southwest to peak sharply at about 0500 MST on November 18. This was approximately 40 hours previous to the observation discussed in this section. As noted in Table 1, approximately two hours of observing time were obtained the evening of November 17, ten hours before the maximum. However, no pulses were observed which could be attributed to meteor impacts during that two hour period.

4.2 Discussion

From Section 2.3 the expected photon flux at the earth from a meteor with a mass of m grams impacting on the lunar surface is

$$J = 0.05 \text{ m (photons/cm}^2 \text{-}\mu \text{ sec)}$$

The collecting area (A) of the 20 inch refractor is about 2×10^3 cm^2. Hence, the photon flux incident on the PMT is

$$JA = 0.05\ m \times 2 \times 10^3 \text{ photons}/\mu \text{ sec}$$
$$= 10^2\ m \text{ photons}/\mu \text{ sec}$$

Assuming the PMT has a 2.8% average quantum efficiency (from advertised specifications), this flux yields 2.8 m photo-electrons/μ sec leaving the photocathode. A single photo-electron leaving the cathode will produce a voltage pulse at the anode given by

$$V_o = \frac{Q}{C} = \frac{eG}{C}$$

where

e	is the charge on the electron (1.6×10^{-19} coulombs)
G	is the PMT gain ($\sim 3 \times 10^6$), and
C	is the anode stray capacitance ($\sim 1.5 \times 10^{-5}$ μfd)

Substituting these values we find

$$V_o = 3.2 \times 10^{-2} \text{ volts/photoelectron}$$

The voltage at the integrator-filter output is

$$V_1 = \frac{\tau_o}{\tau_1} V_o$$

where τ_o is anode circuit time constant due to the stray anode capacitance (C) and the anode load resistor (R_L), and

τ_1 is the filter integrating time constant.

The anode load resistor is 1.1×10^3 ohms, hence τ_o is 1.65×10^{-8} sec and, by choice, τ_1 is 1.0×10^{-6} sec. Therefore,

$$V_1 = 1.65 \times 10^{-2}\ V_o$$

For 2.8 m photo-electrons leaving the photocathode in one microsecond, the filter output pulse amplitude is

$$V_1 = (1.5 \times 10^{-3}\ m) \text{ volts}$$

The PHA calibration 3.1 mv/channel. Therefore, in terms of the mass of the impact meteor

$$m \approx 2.1\ n \text{ grams}$$

where n is the PHA channel number.

If the conclusion is drawn that the pulses in channels higher than Channel 20 are indicative of meteor impact on the lunar surface, then 49 impacts were observed over an interval of 141 minutes. These pulses would then correspond to meteor masses between 42 and 227 grams.

5.0 CONCLUSIONS

In the present program an instrument was developed and fabricated for the purpose of observing meteor impact on the dark moon from a single observing station. A total of approximately 5 hours observation time was obtained with the instrument during a field trip at the Lowell Observatory in November, 1966. Of these five hours, approximately two hours of viewing was performed prior to the peak of the Leonids and approximately three hours after the peak.

A total of approximately 49 counts were observed which were above the level expected from fluctuations in background level. These counts could not be induced by any reasonable artificial means immediately following the data runs and can be attributed only to actual meteor impacts or very unusual instrumental effects. All of these counts were observed in the data run which followed the peak in the Leonid shower by about 40 hours.

It is recommended that additional observations be made utilizing the instrument developed for the measurements described in this report in order to verify the apparently positive results obtained. It is concluded that viewing quality for this experiment would probably not be worse from a station such as Harvard Aggasiz than that encountered at Flagstaff. It is thus recommended that viewing around two successive new moon periods be performed at the Aggasiz 61 inch reflector telescope.

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